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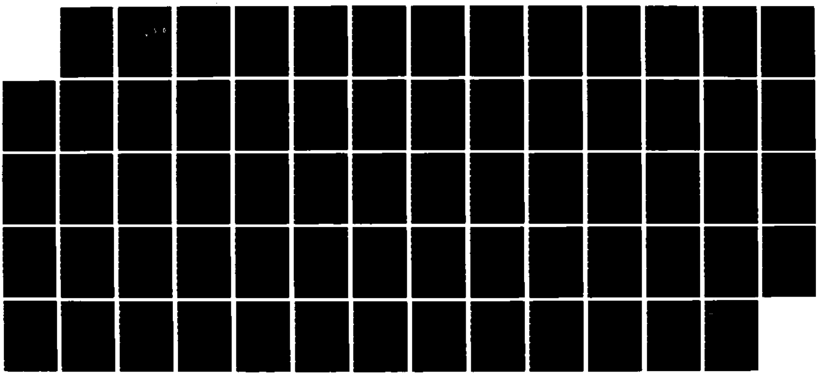

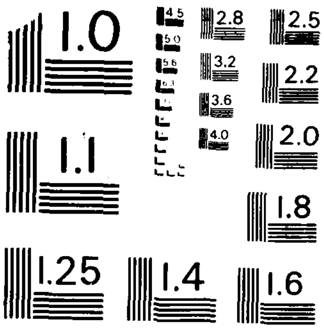

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THESIS

A TAO ASW EXPERT SYSTEM PROTOTYPE

by

Gareth Andrew Gostlow
September 1986

Thesis Advisor: Douglas E. Neil

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The expertise required by Tactical Action Officers in a modern Anti-Submarine warfare environment of complex weaponry, minimal reaction time and arduous conditions at sea necessitate training and experience that is both exhaustive and progressive. For these officers to be effective in making accurate and timely decisions so as to effect the most appropriate responses, they must have ready access to current tactical doctrine and system performance statistics. In time of war there is no time to allow a junior Tactical Action Officer to progress to a level of competency: he must be a reliable, capable, fully functional warfare team member at the outset of his tour.

This thesis presents a prototype Artificial Intelligence model of the TAO ASW decision making process using an expert system development tool run on a microcomputer, to train fledgling TAO's with an outlook to the potential development and capability of an operational expert system.

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A TAO ASW Expert System Prototype

by

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Lieutenant Commander, Canadian Armed Forces
B.Sc., University of Toronto, 1972

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
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ABSTRACT

The expertise required by Tactical Action Officers in a modern Anti-Submarine Warfare environment of complex weaponry, minimal reaction time and arduous conditions at sea necessitate training and experience that is both extensive and progressive. For these officers to be effective in making accurate and timely decisions so as to effect the most appropriate responses, they must have ready access to current tactical doctrine and system performance statistics. In time of war there is no time to allow a junior Tactical Action Officer to progress to a level of competency; he must be a reliable, capable, fully functional warfare team member at the outset of his tour.

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DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

A. PROBLEM DEFINITION

The Tactical Action Officer (TAO) in a Naval ship is, for a variety of reasons, prone to errors of commission or omission, or in the best case, selecting less than preferred alternatives under the prevailing circumstances. It is mandatory that the TAO, consistently, after accurate threat analysis, initiate the most desirable threat neutralization procedure.

Although the cause of the aforementioned inconsistencies are numerous and complex, one of the main contributing factors is the obvious lack of experience and the subjective and often biased training received by TAO's.

In order to rectify this deficiency, it is highly desirable to implement a reliable and consistent tactical decision making 'aid'. Necessarily, the system would facilitate the transfer of knowledge from tactical experts to sophomore TAO's via an expert system.

B. BACKGROUND

Modern weapon system technology minimizes allowable TAO response time to effect the appropriate countermeasure or counteroffensive. The myriad of present day weapons systems and tactics further exacerbate the problems faced by fleet TAO's.

Additionally, TAO's are required to make and execute these decisions in an environment that is less that ideal under conditions of fatigue, high noise and extreme tension.

TAO development is an exhaustive training process including formalized academic, technical and on-the-job training. A prerequisite to this training is normally a minimum of fours years of prior training which includes at-sea, simulator and formal institutional instruction. The most realistic and probably the most effective training and assessment of TAO effectiveness in peace time, is achieved by participation in fleet exercises during at sea deployments. Although this may be the most desirable method of providing experience and training to TAO's, scheduling and resource costs are prohibitive. TAO training is very costly, and valuable in situ experience in many cases is at best fortuitous.

In addition, Naval officer career progression necessitates minimum TAO tour duration. Experienced, qualified TAO's, relieved of their duty by more junior less experienced TAO's, progress to staff appointments and the cycle continues.

C. THESIS OBJECTIVE

This thesis attempts to develop a "knowledge based" expert system prototype of the TAO decision making process in the area of Anti-Submarine Warfare (ASW). The developed prototype is intended as a tool for feasibility and suitability study of the appropriateness of expert systems in ASW tactical decision making.

The system will interactively consider environmental and tactical factors included in its knowledge base and subsequently advise the TAO of the recommended course of action in a limited scale naval encounter. It is anticipated that the prototype will be of use in a training environment and potentially, with further development and system integration be of operational use.

D. WHY USE AN EXPERT SYSTEM?

1. Domain Complexity

The arsenal and sophistication of modern submarine launched anti-ship weapons and tactics, under varying environmental conditions and engagement rules, complicates the TAO's threat analysis and optimal course of action selection problem. Reaction time being limited, it is unlikely that, even if he capable of total recall, the TAO can adequately consider all potential adversaries and respond optimally.

Additionally, sustained periods of warfare environmental conditions inevitably induce TAO fatigue, which further contribute to less than the optimal TAO response.

2. Reaction Time and Information Accuracy

Computer and data storage/retrieval systems facilitate the necessarily rapid verification of ship sensor received data. Sensor inputs can be quickly compared to on-line data/platform libraries, thus reducing the potential for human interpretive error in raw data evaluation and minimizing inordinately lengthy confirmation

time delays. Nonetheless, the computer aided identification systems, although instrumental in confirming sensor accuracy and identification, do not correlate all of the additional and conjunctive factors that must be simultaneously evaluated by the TAO in determining the preferred course of action; thus the requirement for an expert system.

3. Response under Pressure

Computer based systems, unlike humans, are capable of consistent performance in the data search of immense fact libraries and decision derivation, despite intense external pressures. The TAO on the other hand is potentially likely to omit or confuse vital statistics and facts, that could prove immensely costly and possibly fatal, under stressful and time constrained conditions.

4. Knowledge Transfer

As previously stated, the Naval officer career progression necessitates tour lengths of relatively short duration; TAO's are continually being replaced by juniors after they have just become proficient through experience at sea.

The expert system would allow for the complete and accurate expertise transfer to the incumbent TAO. The valid experience and accepted tactical doctrines that are instrumental in the development of the expert system knowledge base would be available to the replacement TAO, thereby preventing some of the discontinuity and reducing time to develop operational competency.

5. Decision Making Logic

Expert Systems allow for, upon request, examination of the line of reasoning and methodology used in the formulation of intermediate and final decisions.

II. DESCRIPTION OF DOMAIN KNOWLEDGE

A. THE TAO CONCEPT

A TAO is that Officer on watch in a Navy ship who is qualified, and designated in writing by the Commanding Officer of the ship, to manage ship's personnel and equipment, including all ship's weapon systems and the propulsion plant, in time of war or peace, consistent with the command policy and the policy of higher authority. He is specifically authorized to take direct action, using ship's weapons, Combat Air Patrol (CAP) under ship's control and/or Electronic Countermeasures (ECM) to fight the ship when the tactical situation demands. The TAO has the responsibility and authority to defend the ship and is responsible directly to the ship's Commanding Officer for his actions and decisions. He is experienced in tactical decision making in a Naval environment.

1. Qualifications

The TAO's qualifications should include, for example, the following [Ref. 1] :

* A background of knowledge and experience in Anti-Air-Warfare (AAW), Anti-Submarine-Warfare (ASW), Electronic-Warfare (EW), Amphibious-Warfare (AMW),and Anti-Surface-Warfare (ASuW), including a detailed knowledge of his own ship's weapons and propulsion capabilities and limitations.

* A good knowledge of the characteristics, capabilities and

limitations of fighter, attack, ASW, EW, and Airborne Early Warning (AEW) aircraft, their associated weapons systems and their means of employment.

* Familiarity with AAW, ASW, EW sensors including radar,sonar, and Electronic Surveillance Measures (ESM) equipment employed by his own ship and other units operating in the area.

* A familiarity with available intelligence on pertinent, potential enemy tactics and doctrines and substantial knowledge about the capabilities and limitations of enemy hardware resources, including platforms as well as Anti-Ship-Cruise Missiles (ASCM's).

* Knowledge of the procedures utilized for air intercept control (AIC) and for CAP/missile coordination.

2. Organization

There are several different implementations of the TAO concept in the Navy today. A specific TAO organization depends on the ship type, the ship weapons suite and the ship's mission. A sample TAO organization is provided in Fig. 1 below for illustrative purposes only. It shows only the basic command and control relationships.

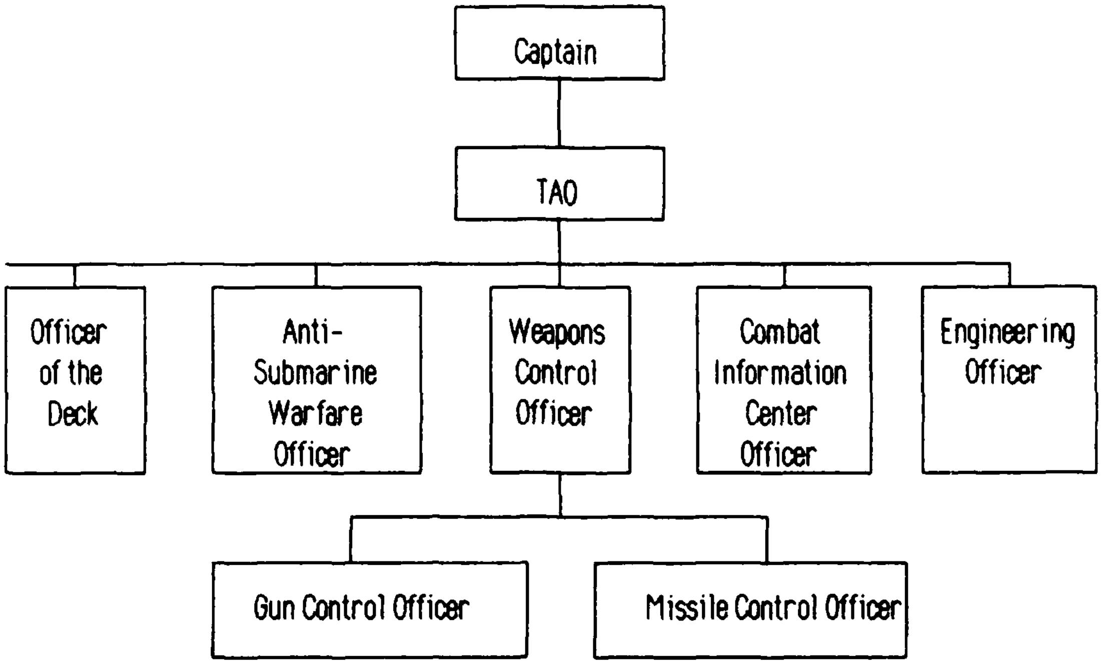

Figure 1 TAO Command and Control Diagram (an example)

B. ENVIRONMENT AND THE TAO DECISION MAKING PROCESS

1. Environmental Factors

Tactical decisions and responses are the ultimate responsibility of the ship's Commanding Officer, but rely heavily upon the input and actions of the TAO. Despite the increased sophistication of weapons/sensors and shipboard automation in areas of information processing and decision aids, it is the TAO who must make the final analysis and subsequent recommendations or initiate the most appropriate action in the absence of the Commanding Officer. These analyses and decisions are the result of the TAO's experience, analytical aptitude and must be consistent

with the doctrines and engagement rules in force at the time. In order to competently make the appropriate decision, he must also recall or readily access reference data, specifically the order of battle attributes of both friendly force emitters and adversaries radiators and weapons systems.

The TAO must be constantly aware of the readiness status and capabilities of his own ship's weapons, sensors, propulsion system and the "Rules of Engagement" under which he is operating, as well as policy established by his Commanding Officer. Additionally, he must be an expert in the status, characteristics and capabilities of "friendly" platform weapons and intercept systems. He must also be well-versed in and have immediate access to tactics and engagement strategies. Further, he must consider less readily defined factors such as prevailing weather and sea conditions, visibility, the political situation world-wide and in the present operating area and be cognizant of the presence of "neutral" or commercial shipping and aircraft. Add to this the consideration of geographical proximity to friendly or hostile land masses, logistic support and operating bases.

2. A Typical Scenario at Sea

In order to illustrate some of the aforementioned concerns the following situation can be constructed:

During an at-sea exercise with poor visibility and severe weather including high winds and heavy seas, the ship having

been on an ASW patrol for several days with no detections receives intelligence information of an anti-ship firing enemy submarine operating in the patrol area. The submarine described is believed to be of the type that is required to surface prior to missile launch. The ship's sonar capabilities have been seriously degraded by the high ambient noise generated by the the heavy seas and the poor bathymetric conditions of the operating area. In addition, the masking noise levels are increased by the underwater sounds produced by commercial shipping in the area. The ship's crew is tired and less than enthusiastic as a result of the extended patrol and severe weather induced ship motions.

Although the sonar section on watch is staffed by competent, experienced operators and technicians with an impressive record of sonar contact detection and classification even under arduous conditions, their vigilance, enthusiasm and effectiveness have been severely lessened by the lack of previous detections during the long patrol and the fatigue caused by the patrol duration and conditions.

The TAO is informed by a maritime patrol aircraft operating in consort that a contact is held on their sonobuoy pattern which is generating sound frequencies corresponding to the type of submarine for which they are searching. The reported range is within the submarine's missile firing range.

The Electronic Warfare (EW) section, whose past performance has been commendable, reports no detections of the anticipated submarine's missile acquisition radars.

Similarly, no radar detection of surface or airborne contacts have been made and no sonar contact is reported.

The TAO assesses that it would be most unlikely if not virtually impossible for the submarine to surface in the present sea state without broaching let alone have its missile doors open in preparation for launch. Nonetheless, the TAO is forced to make some decisions and make them quickly. What should he do?

Despite the outcome, the above scenario is indicative of the reliance placed upon the TAO to expediently and accurately perceive, correlate and respond to numerous diverse and often contradictory information in the evaluation of options and the formulation of judgement decisions. All of these necessitate the TAO being an expert in data management and decision making.

C. TEMPORAL PRESSURE AND INFORMATION OVERLOAD

The Combat Information Center (CIC), during an actual or simulated enemy engagement, receives vast, diverse and continual sensory inputs. In addition to voice radio circuits, a primary means of tactical and administrative information reception, numerous verbal reports are generated by on-watch personnel, and equipment operating noises are but some of the contributions

to high environmental noise levels. All of the reports must be heard, acknowledged, analyzed and responded to. Simultaneously, the TAO must be cognizant of his own ship's readiness status, position and movements as well as those of the disposition and actions of consorts. He must be able to pragmatically assess and prioritize all inputs without being inundated or overloaded in order to logically and rationally evaluate the most appropriate course of action consistent with his own ship(s) safety and the enemy's anticipated actions.

In such an environment as this, and considering the myriad of ever-changing arsenal of existing weapons, sensor and platform capabilities, it is understandable how tactical doctrine can be forgotten, or weapon/sensor/platform attributes confused. Frequently, time constraints force the response prior to complete, accurate analysis. Any oversight or erroneous deduction can precipitate potentially catastrophic results to the ship, the battle force and ultimately the tactical or strategic effort.

III. ARTIFICIAL INTELLIGENCE

The purpose of this thesis is to develop an "Expert System", a specific area of *Artificial Intelligence*.

A. BACKGROUND

The term "*Artificial Intelligence*" (AI) was coined in 1956 by Professor John McCarthy of MIT.

From the beginning the term "AI" has aroused a good deal of controversy, especially since in 1956 many believed that intelligence was based upon "smart reasoning" techniques that would soon be found and would produce intelligent computers.

Now 30 years later, no single, powerful mechanism responsible for intelligence has yet been found. Despite this, AI has prospered, largely because AI technology had led to a number of useful results.

AI researchers, in defining AI, now avoid the question of intelligence. There are as many definitions of AI as their are publications about AI; the following are but a few:

* Making computers do things that would be considered intelligent if done by human beings. What these things are, are constantly changing. For instance 30 years ago, playing chess at a master's level was a typical goal for intelligent computing. Now this has been done. Should we now define human intelligence to exclude chess?

* The study of processes that underlie thinking and perceiving and their implementation on computers. The possibility exists that AI research may eventually add to our understanding of human intelligence.

* A branch of computer science that investigates symbolic reasoning and symbolic knowledge representation for use in machine intelligence.

Most AI systems have common underlying attributes. Firstly, there appears to be no single reasoning algorithm or mechanism that can adequately furnish intelligence to computers; AI as it is presently known makes use of numerous techniques selected for specific applications. Secondly, the basis of most AI systems today is the representation and application of the specific problem domain; if knowledge required in specific and narrow fields of human expertise can be adequately represented, the AI solution is feasible.

AI systems already available and undergoing further research efforts include:

* Expert Systems
* Automatic Programming
* Natural Language Interaction
* Speech Input and Output
* Intelligent Robots
* Image Processing and Analysis

B. EXPERT SYSTEMS

1. Definition

Expert Systems, a branch of AI, use knowledge and inference procedures in a "rule-based" program shell to determine solutions to specialized problems.

Feigenbaum [Ref. 2:p. 1], a pioneer in the field, defines expert systems:

> An "expert system" is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field.

The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in the field. The "heuristics" are mostly private, little-discussed rules of good judgement (rules of plausible reasoning, rules of good guessing) that characterize expert level decision making in the field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base that it possesses.

Knowledge based systems rely on "heuristics"" in order to limit the sequential search and subsequent knowledge examination of applicable rules in an extensive database leading to the ultimate decision.

As defined by Feigenbaum and Feldman [Ref. 3:p. 6] :

> A heuristic (heuristic rule, heuristic method) is a rule of thumb, strategy, trick, simplification or other kind of device which drastically limits the search for solutions in large problem spaces. Heuristics do not guarantee an optimal solution; in fact, they do not guarantee any solution at all; all that can be said for a useful heuristic is that it offers solutions which are good

> enough most of the time.... The payoff in using heuristics is greatly reduced search, and therefore, practicality. Often, but not always, a price is paid: by drastic search limitation, sometimes the best solution (indeed, any or all solutions) may be overlooked.

The expert system technique allows one to begin with a partial specification of what humans do. Then, by working with the knowledge base and inference techniques built in the expert systems, the system is improved at the knowledge level rather than at the level of program design and implementation. The expert system approach can thus save significant development time that would have been required in the "shell" program production.

2. Structure

Most commercially available expert systems today use some form of rule based system in their basic structure.

A rule based system maintains expert knowledge in the form of rules in the computer memory. The rules are acquired from human experts and normally are of the form IF: *object attribute* THEN: *result/hypothesis*. For example, a rule for a passive sonar analysis may be:

IF: Observed tonals are below 50 Hertz

THEN: The source may be a propellor.

The systems normally operate in either of two ways:

* Forward-Chaining: rules are applied to the facts or object

attributes to formulate a hypothesis.

* Backward-Chaining: rules are applied that support the hypothesis.

Most expert systems offer the user an explanation of the reasoning process in the hypothesis development and display confidence values upon request.

3. Properties

Expert systems commonly have the following properties:

* Designed to provide solutions to difficult problems in a manner similar to that of a human expert.
* Rules for the system are derived from human experts by knowledge engineers and modelled by computer scientists.
* During and subsequent to rule processing, logical reasoning for decision making is presented.
* Systems allow for additions to and modifications of the knowledge base to permit system growth and accuracy enhancements.
* Systems have the ability to consider multiple competing and supportive hypotheses.
* Designed to be user-friendly: human interaction is logical, pragmatic and allows for natural language input and output.

4. Limitations

In their present state of development, expert systems are subject to a number of limitations:

* Expert systems have limited scope. The field of expertise is limited to the area for which they were designed. Rule based expert systems are applicable to situations that can be modelled by rules.
* Because the knowledge must be translated into a specified

format prior being entered into the database, there is an obvious lack of flexibility.

* Expert systems have a severely limited learning capability. The knowledge must be manually input into the system without benefit from previously developed hypotheses.

* Present systems are limited in their ability to reason, examine problems from a different perspective, or determine cause and effect.

IV. TAO ASW PROTOTYPE DEVELOPMENT PROCESS

A. INTRODUCTION

The requirement for a TAO ASW Expert System Prototype was established in Chapter I. The phases of development of the prototype were derived from Ref. 4 as depicted in Figure 2 below.

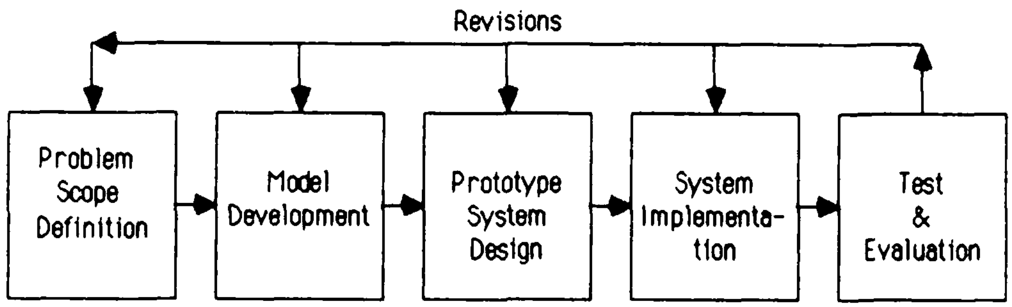

Figure 2 Phases of TAO ASW Expert System Development

B. PROBLEM SCOPE DEFINITION

Perhaps the most difficult phase is the determination of how to limit the scope of the problem defined.

The problem to be modeled, although an extremely complex one of tactical decision making, necessarily required precise, clear definition. The model must accurately reflect the human thinking process in the solution of multifaceted and complicated problems.

The route/path to the most plausible, optimal solution is not static nor necessarily reproducible under apparently similar conditions; it is reliant upon numerous, frequently changing parameters. In order to simplify, and more precisely model the

analysis-action process, it was decided to assume that the TAO's ship was independent or in command of all other consorts/resources, so as not to be constrained by higher local authority. A scenario of but one opposing submarine was assumed adequate for establishing the utility and feasibility of this prototype. Necessarily, this first stage of the expert system development is primarily concerned with data collection from the environmental and expert domains. To fulfill this requirement, several experienced TAO qualified Officers were interviewed to gain their insight, combined with the author's extensive experience and training in a TAO role at both the single ship and squadron level. In addition, since the intent of this study is to determine the feasibility of the ASW expert system prototype, the domain was restricted to limited assets and opponents in a finite, simulated and unclassified engagement.

C. PROBLEM DEPICTION

In order to adequately represent the TAO decision making process, the complexity of the domain was artificially rationalized into modules as depicted in Figure 3 [derived from Ref. 5] below:

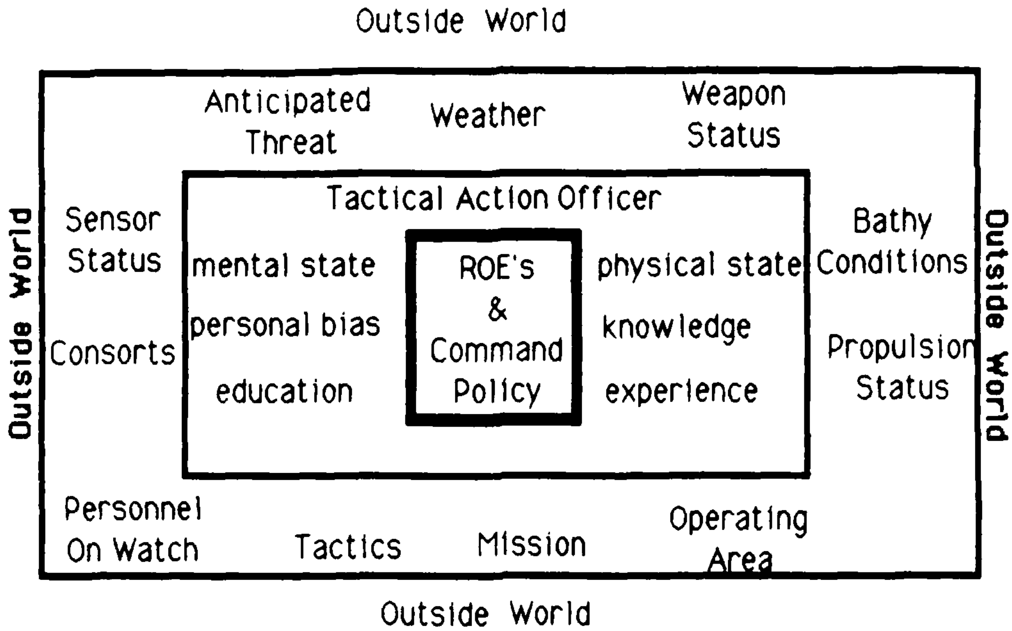

Figure 3 The TAO Environment

1. <u>The Core</u>

The box at the center of Figure 3 is the core of the model. The core contains the Rules of Engagement (ROE) and the standing orders of the ship's Captain. These policy directions, established *a priori* are promulgated by higher authority, and as such are not within the TAO's purview to change but are essential elements of his decision formulation and response implementation. The policy restrictions within the core may be changed frequently and on short notice, as the tactical/political situation changes, by higher, controlling authority. The TAO must restructure his analysis and responses to comply to the newly established constraints.

2. <u>The On-Watch TAO</u>

Depicted external to the core, the next larger box is representative of an individual TAO's knowledge, experience and mental acuity. These TAO attributes in conjunction with established policy directed from within the core, comprise the knowledge database for TAO decisions and responses.

3. Environment

The largest box is representative of the immediate environment within which a TAO must function.

The region outside this box has arbitrarily been defined as outside world - the distinction being one of mere physical distance - but both areas can be linked or overlap in an "action-reaction" relationship.

4. The "Action-Reaction" Process

The dynamic TAO decision making process is stimulated by either activity or lack of activity in a TAO environment. Both 'TAO - Core' and 'TAO - Environment' interfaces are vital to "action-reaction" pairing in the model and thus, the decision making process. Stimuli are transmitted across these interfaces prompting TAO responses.

5. Performance Assessment

The measure of appropriateness and effectiveness of the TAO reaction, can be measured arbitrarily but will necessarily be dependent upon the quality of the core and more importantly the second box - the TAO. This reaction/response assessment will vary with individual TAO's, despite apparently identical stimuli, since it

is responsive to the individual attributes contributing to this knowledge database.

As represented in Figure 4, the process depicted in the model, (see Fig. 3), can be functionally reduced to individual elements of a hierarchy and modelled for the development of the TAO ASW expert system prototype.

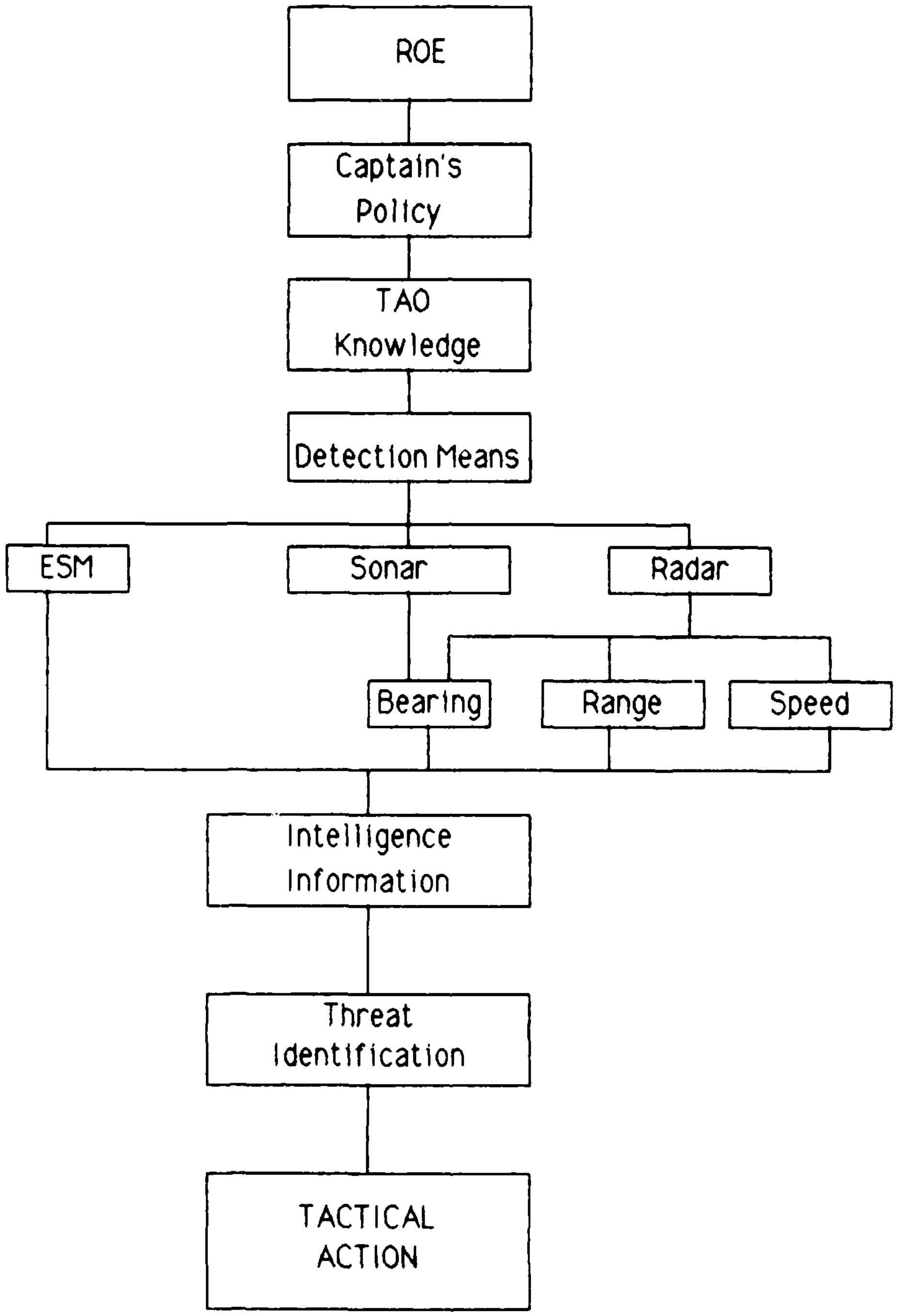

Figure 4. Hierarchy of a TAO Expert System Knowledge Base

D. SYSTEM DESIGN

The purpose of the expert system prototype is the simulation, minimally in a training environment, of the TAO decision process for an offensive against or defence from an enemy submarine. The ultimate aim is development of an operational ASW prototype expert system which will recommend appropriate courses of action in response to environmental stimuli - contact range, bearing, speed etc.

1. Tactical Training Model Hierarchy

In order to effect the model, a framework or hierarchy representative of elements of the TAO training system is proposed. Domain complexity precludes inclusion of all environmental inputs (i.e. political situation, geographical location, enemy force disposition, etc.) in this prototype model but complete inclusion is feasible in a fully developed and integrated model.

Although not all inclusive of environmental stimuli, Figure 4 is representative of the hierarchical strategy used in the prototype development.

2. Program Architecture: Forward- vs. Backward-Chaining

In the consideration of several computer program architectures, the process of " forward-chaining" versus "backward-chaining" was assessed to determine which method best reflected the TAO decision formulation process.

In a "forward-chaining " process, the expert system designer reduces the large-scale problem into smaller, less complicated sub-problems. The result of one sub-problem is subsequently used as an input to the next more complex sub-problem and so on until the ultimate decision is reached.

The goal orientated "backward-chaining" system considers, sequentially, a set of candidate general solutions, seeking knowledge base rules that support a particular solution.

3. Architecture Selection

The knowledge base required to adequately model human, cognitive thinking as in the case of the TAO decision process, did not not lend itself well to common computer programs of the " input-process-output" type. The human analysis process is often random as opposed to sequential, and involves multiple, seemingly unrelated stimuli evaluations. Despite the self-imposed limited scenario for the model, the task of ASW defence or prosecution remains complex. The final decision to launch a torpedo or initiate torpedo deception procedures, for example, is predicated upon several intermediate steps in response to the analysis of extensive tactical and statistical data. Because of the numerous alternatives and time constraints, a fast and efficient architecture was desirable that "short-circuited" itself to avoid delays caused by the consideration of all possibilities yet was directed to the optimal solution.

Because the TAO determines and executes solutions to a specific problem (such as an inbound torpedo) the "backward-chaining" method was selected as the preferred architecture for use in the prototype development. In most cases, the goal is clearly defined. In the case of an inbound torpedo, the aim is to minimize the potential for damage by torpedo avoidance. Although this is but a single goal, multiple, supportive goals are possible in accordance with policy and rules of engagement.

Additionally, the TAO, through previous training, experience and reference documents, has available pre-defined candidate solutions. This situation is similar to the "backward-chaining" problem solving architecture.

4. Knowledge Base Optimization

With the "backward-chaining" process in mind, the system was developed from a desired objective and constructed from a "bottom-up" series of events that would likely precede the preferred action. The knowledge base hierarchy is implemented in a similar manner; at program start, the expert system is initialized with facts by the system designer. Subsequently, as required by the system, the user is prompted for additional data requisite to the formulation of the solution/decision recommendation.

The program designer must therefore structure the program input selection lists, both in content and the sequence in which the lists are presented. User interaction must be logical, sequential and

designed commensurate with the system user's knowledge and background.

Efficiency (speed) was enhanced by structuring the knowledge base to allow heuristic search methods, and to facilitate program utilization of inherent rules to discern the appropriate path to follow when confronted with competing alternatives.

5. *Development Tool Selection*

Available development tools were reviewed during this phase. In addition to traditional AI languages, such as PROLOG and LISP, expert system development tools such as EXSYS, EXPERLISP, RULEMASTER, INSIGHT 2 and INSIGHT 2+ were evaluated.

INSIGHT 2+, a commercially available - at a cost of $995 - rule based expert system development tool was selected to implement the ASW Expert System Prototype because of the following features [Ref. 6] :

1. Format simplicity.
2. Program compilation to increase speed.
3. Simple control structure.
4. Natural reasoning process.
5. Flexibility - additional rules may be added to enhance sophistication.
6. Capability of both forward and backward chaining.
7. Ease of knowledge base development languages - Pascal or INSIGHT 2+ Production Rule Language (PRL).

INSIGHT 2+ additionally uses natural language (English) like commands, is supported by excellent, comprehensive

documentation and on-screen user assistance. Further, INSIGHT 2+ facilitates prototype development through excellent on-line editing capabilities.

6. System Customization/Modification

The system should be easily modified so as to meet the requirements of the individual TAO as well as the domain. Industry production software strives to develop software that is tailored to the intended user. The model developed was necessarily limited in scope and unclassified in nature. Program customization to enhance precision or to suit individual TAO's, ship types, or changing tactical doctrines is attainable with simple modification to the production rules.

7. Knowledge Base Maintenance

As changes occur - weather, intelligence information, tactics, battle force configuration - the TAO can perform system updates or maintenance. To facilitate rapidly changing parameters such as weather, bathymetrics and intelligence, separate databases could be established and linked to the main program thus reducing the potential for undesirable "ripple" effects and system down time.

V. TAO ASW EXPERT SYSTEM IMPLEMENTATION

A. CONFIDENCE VALUES

To further enhance the reliability of the system produced decisions, confidence prompting is used. As is the case with most "production rule" type expert system development tools, INSIGHT 2+ offers the capability to query the user on the confidence that is assigned to his selection or response to rules, statements or object attributes.

The confidence values are integers, assigned arbitrarily and defined as follows [Ref. 6] :

Known: 0-100 ; 0 - no certainty, 100 - absolute certainty

Unknown: -2

Not yet known: -1

During the development phase, the program designer establishes a "threshold" value for each production rule. The confidence values assigned by the system user must exceed this threshold for the system to evaluate the response to the rule as being true.

For example, if the user's assigned confidence value is 70 and the threshold is 50, the rule is assessed as being true with a confidence of 35 (70 times 50 divided by 100). Conversely, if the user assigned confidence value is 40 with a threshold of 50, the rule is deemed false and assigned a confidence value of 0.

B. PRODUCTION RULE GENERATION

The TAO knowledge database previously assimilated was analyzed into elements of the hierarchal structure in preparation for translation to the "IF - THEN" production rule format of the expert system prototype.

The knowledge domain is comprised of numerous alternatives and essential quantifiers/qualifiers. In order to be effective, the system must, as required, query the user for these additional input parameters. These amplifying inputs and their presentation sequence are of utmost importance in the development structure of the knowledge base.

1. Knowledge Translation

In order to create a system that produces valid recommendations to the TAO, the expansive knowledge and statistics of the naval ASW tactical domain must be imparted to the knowledge base of the expert system.

The knowledge base is comprised of a collection of production rules in the form of " IF - THEN" format pairs, developed from the tactical knowledge domain. The "IF" part of the "IF - THEN " pair evaluates the validity of an object attribute or condition; the evaluation being true concludes that the "THEN" part is accepted subject to the confidence values previously described. The system then uses the "backward-chaining" process to examine other rules leading to the recommendation derivation.

The system records the user inputs, rule assessments and path followed to the final conclusion or recommendation. The user may, as desired, examine the session, program flow and the reason for rule or ultimate conclusion decision. As an example of the system process, the user may be presented with the following selection options:

ESM detection is:

1. navigation radar
2. air search radar
3. missile guidance radar

A response of 3 (missile guidance radar) would cause the system to solicit amplifying parametric entries to assist in target identification and characteristics followed by with an alert and appropriate recommendations as required.

2. System Efficiency

The design phase identified a requirement for the system to be able to "short-circuit" to prevent or limit the pursuit of unreasonable solution paths. The developed prototype was constructed to examine only rules pertinent to the present problem, thereby reducing search and recommendation times.

Valuable time would be lost in examining, for example, paths that lead to a possible recommendation of firing a torpedo at an inbound submarine launched anti-ship missile. The first priority of the system would be missile defence and effecting recommendations in keeping with the immediate problem situation.

VI. TACTICAL TRAINING PROTOTYPE PARAMETERS

A. SYSTEM CHARACTERISTICS

The TAO ASW Expert System Prototype was developed using the INSIGHT 2+ expert system development tool. The expert system prototype is compiled and run on an IBM or compatible minicomputer system.

The INSIGHT 2+ system requires 192K bytes of RAM, but a minimum of 448K bytes is recommended in order to have access to full functionality of the envisioned operational system, accessing external programs from within the knowledge base (external program activation). The amount of available memory in the computer above 64K bytes up to 384K bytes also determines the size of the knowledge base source capable of being run. An IBM computer with 512K bytes of RAM will accommodate a knowledge base comprised of some 1752 rules or facts.

B. SYSTEM OPERATION

The TAO ASW expert system when run begins by reading all rules in the knowledge base, and prompting the user for amplifying information or inputs as required. The selection menus presented to the user seeks selectable inputs, either single or multiple; the program will repeat the user query if the user selects or attempts to input other than the presented selections.

The knowledge base production rules are structured so as to direct the most desirable path when the system is confronted with competing alternative paths.

The developed prototype does not claim to be exclusively correct in the path chosen to decision development. As with the human cognitive process, the decision to fire a torpedo can be arrived at in numerous different ways or sequences; the one presented in this prototype is merely to demonstrate how an expert system can be structured to reach a similar conclusion. The purpose of this work was to establish the feasibility of the development and potential use of such an ASW expert system.

VII. SYSTEM PERFORMANCE ANALYSIS

A. BACKGROUND

It must be emphasized that due to the severe limitations of scope and the requirement for an unclassified project, it was anticipated that the prototype would not completely resolve the deficiencies identified in the problem definition phase [Chapter I].

B. TEST AND EVALUATION

Time limitations precluded a detailed, structured test and evalutation phase of this project.

In order to validate the TAO ASW expert system prototype, the system was demonstrated to and evaluated by a limited number of TAO qualified officers and professors at the Naval Postgraduate School. Test candidates were provided with system operating instructions [Appendix A], the program master disk and subsequently, opinions and comments were solicited on the following system attributes:

* ease of use
* accuracy of decisions/recommendations
* logical reasoning presentation
* sequencing of inputs, rules and facts
* training potential
* operational potential
* timeliness of decisions

The responses provided the following preliminary assessments of the prototype capability to meet the design objectives.

1. Complete and Accurate Decision Analysis

Sequential rule processing by the prototype system ensured a thorough, structured input of all parameters involved in the problem analysis, prior to recommendation presentation. Although some subjective interpretation is occasionally required by the user, accuracy of analysis was maintained by menu-driven selections being the only allowable user inputs.

2. Knowledge Transfer and Decision Logic

Although limited in the developed prototype, the knowledge base imparted to the prototype system was readily accessible to the user, thereby facilitating the transfer of knowledge from "experts" to junior TAO's via the prototype system production rule database.

Upon request, the developed prototype will respond to user queries and present the logic employed or path leading to recommendation production. This facility enhances the user's understanding of prerequisite or conjunctive events necessary to decision formulation.

The prototype was produced with minimal costs, as could a training version complete with ancillary tactical procedure and weapon/sensor parameter databases linked to the main program. Such a version would reduce present TAO training costs incurred

by subjective instruction methods, yet ensure thorough, unbiased training.

3. Reproducible Results

The methodical, structured inputs and user responses demanded by the prototype system produced redundant decision results regardless of user background, physical/mental condition or personal bias.

User-system performance evaluation was limited to laboratory conditions only; time constraints precluded evaluations "at-sea" or under variations of ambient conditions such as light, noise etc.

4. Reaction Time Limitation

Time required to develop presented decision recommendations was the most serious shortcoming of the prototype system. Manual inputs and option selections required by the user were the source of these inordinate delays.

In a training version of the system, these pragmatic inputs are necessary to ensure TAO thoroughness in the decision process. Time constrained decisions could be achieved by the use of an initialization module to input environmental, intelligence data etc. prior to system use and by the development of appropriate weapon/sensor interface modules for automated inputs.

VIII. SYSTEM APPLICATION

A. A COMPUTER-AIDED TRAINING TOOL

The TAO ASW Expert System prototype developed demonstrated the feasibility and value of such a system in the transfer of knowledge previously acquired by "experts" in ASW to junior, less experienced TAO's. In addition, a fully developed system would be invaluable as a method for senior officers to review tactical procedures, prior to resuming tactical duties thereby significantly reducing the present costs of refresher training.

B. REAL TIME OPERATIONAL APPLICATIONS

It is conceivable that a substantially enhanced, comprehensive and integrated expert system has the potential for operational utilization. Prior to conception, several non-trivial issues would first have to be addressed.

1. System Response Time

The TAO ASW prototype requires manual inputs, interpretations and translations by the user, a source of serious delays in the final recommendation processing time. Construction of in-depth databases, such as threat parameter libraries, with which the main expert system program would automatically interact would enhance response time. Maintenance of and

modification to data libraries would be simpler and less prone to impacting the integrity of the main expert system.

2. <u>Total System Integration</u>

In order to provide real time information to the TAO, the system would require full integration into the ship sensor and weapon command system. This would enable the expert system to maintain a current status at all times and not lag awaiting manual inputs. The design and implementation of appropriate system interfaces would be no simple task but is essential to operational acceptance of such a system.

3. <u>System Reliability</u>

Time constraints precluded the thorough test and evaluation of the developed prototype. System testing was limited to a few TAO qualified officers and professors at the Naval Postgraduate School. The prototype system requires numerous enhancements and a much more intense, structured test and evaluation phase to ensure reliability.

A fully developed system that provided real time decisions and recommendations would need exhaustive testing, both in the laboratory and under operational conditions, to ensure reliability prior to operational acceptance.

IX. CONCLUSION

The preliminary results of this project sufficiently demonstrated the requirement for further feasibility studies and potential benefits of knowledge based expert systems in the ASW domain for use by Tactical Action Officers.

The prototype developed, although narrow in scope and unclassified in nature, establishes the potential for a fully configured, integrated system.

This ASW prototype is but an introduction to the future capabilities of such a system that could be expanded to all warfare disciplines.

APPENDIX A

PROTOTYPE OPERATING INSTRUCTIONS

1. Getting Started

To run the prototype, copies of the INSIGHT 2+ Master Disk and the TAOASW diskette and access to a dual drive IBM PC or compatible with minimum random access memory of 256K bytes are required.

If not already initialized, install PC-DOS or MS-DOS operating system (version 2.0, 2.11 or later) in the A drive and power up the PC to effect system boot. When prompted, enter the present date and time, which will be followed by the A> prompt presentation. Remove the boot disk, insert the INSIGHT 2+ Program Master diskette in the A drive and the TAOASW diskette in drive B. Type I2\TAOASW <ENTER>.

The INSIGHT 2+ program will load indicated by presentation of the INSIGHT 2+ logo, and subsequently, the TAO EXPERT SYSTEM PROTOTYPE title page will be presented.

2. A Prototype Training Session

To begin the training session depress the F3 [STRT] key. The system will present the user with descriptive input requirements and questions for responses. As responses are entered, the prototype will generate and display recommendations. To continue with the session, depress the F2 [CONT] key, unless otherwise directed. Multiple choice questions are responded to by moving the

cursor over the desired choice(s) and typing <ENTER>; when all selections are complete, depress the F4 [DONE] key.

While using the program, the user can obtain the reason(s) for the requested input and the line of reasoning being pursued by depressing the F6 [WHY] key.

At the end of the session, by selecting the reports function, key F6 [WHY] followed by the F6 [RPTS] again and selecting any of the self-explanatory presented options, the user is presented with the line of reason used to develop the conclusions and/or a recording of the session.

To begin another run, depress the F3 [STRT] key at any time while the program is in operation or at the end of a session.

APPENDIX B

PROGRAM LISTING

```
TITLE TAO ASW EXPERT SYSTEM PROTOTYPE DISPLAY
□
□=========================================================
=========================
□=
=
□=
=
□=
=
□=                                TAO ASW EXPERT SYSTEM PROTOTYPE
=
□=
=
□=                                    BY G. A. GOSTLOW, LCDR
=
□=
=
□=                                  CREATED SEPTEMBER 1986
=
□=
=
□=
=
□=========================================================
=========================
□!
□!
□
□GOALSELECT OFF
□CONFIDENCE OFF
□THRESHOLD = 50
□!
□MULTIDETECTION
□ANDASSET
□
```

```
□!------------------------          GOAL          DEFINITIONS------------
---------------------
□1. Action
□         1.1 ENVIRONMENTAL CONDITIONS
□                 1.1.1 TARGET DETECTION
□
□
□!-----------------------------------------------
------------------------
□! INITIALIZATION INPUTS
□!-----------------------------------------------
------------------------
□
□!------------------------------SCENARIO
DETERMINATION          MODULE----------------
□RULE TENSION
□IF STATUS IS TENSION
□THEN ROES ARE in EFFECT
□AND DISPLAY engrls
□
□RULE WAR
□IF STATUS IS WAR
□THEN no roes ARE in effect
□AND DISPLAY  noengrls
□
□RULE EXERCISE
□IF STATUS IS EXERCISE
□THEN training IS scenario
□!ANDTRAINING
□AND DISPLAY train
□
□RULE CONTINUE
□IF NO ROES ARE IN EFFECT
□OR ROES ARE IN EFFECT
□OR TRAINING IS SCENARIO
□THENACTION
□
□!-----------------------------ENVIRONMENTAL
INITIALIZATION        MODULE-----------
□RULEVISIBILITY
```

```
□IF VISIBILITY is GOOD
□THEN VISUAL DETECTION IS POSSIBLE
□AND DISPLAY LOOKOUTS
□
□
□RULE EMCON
□IF EMCON is RESTRICTED
□THEN EMCON POLICY IS SILENT
□AND DISPLAY EMCONSILENT
□ELSE EMCOM POLICY IS TRANSMIT
□AND DISPLAY EMCONACTIVE
□
□RULE BATHYMETRICS
□IF BATHY CONDITIONS are REVERBERATION LIMITED
□OR BATHY CONDITIONS are NOISE LIMITED
□OR BATHY CONDITIONS INDICATE STRONG NEGATIVE GRADIENT
□THEN SONAR CONDITIONS ARE POOR
□ELSE SONAR CONDITIONS ARE GOOD
□
□
□RULE DUCTING-SOUND CHANNEL
□IF SUBSURFACE DUCT is PRESENT
□OR DEPRESSED SOUND CHANNEL is PRESENT
□THEN TRANSCEIVER SETTINGS ARE TO BE CONSIDERED
□AND DISPLAY VDSBODY
□ELSE TRANSCEIVER BODY POSITION
□
□RULE FRIENDLIES
□IF ASSET IS SUBMARINE
□AND ASSET IS VP
□AND ASSET IS HS
□AND ASSET IS CAP
□AND ASSET IS OWN SHIP ONLY
□THEN CONSORTS ARE AVAILABLE
□
□RULE CONDITIONS
□IF TRANSCEIVER SETTINGS ARE TO BE CONSIDERED
□OR EMCON POLICY IS SILENT
□OR EMCON POLICY IS TRANSMIT
□OR VISUAL DETECTION IS POSSIBLE
```

```
□OR SONAR CONDITIONS ARE POOR
□OR SONAR CONDITIONS ARE GOOD
□OR CONSORTS ARE AVAILABLE
□THEN ENVIRONMENTAL CONDITIONS
□
□!-----------------------------DETECTION                    MODULE-------
------------------------
□
□RULE CONTACT  DETECTION
□IF DETECTION IS VISUAL
□OR DETECTION IS ESM
□OR DETECTION IS PASSIVE SONAR
□OR DETECTION IS ACTIVE SONAR
□OR DETECTION IS RADAR
□OR DETECTION IS MAD
□THEN CONTACT DETECTION
□!
□RULE VISUAL  PERISCOPE
□IF DETECTION IS VISUAL
□AND TARGET IS PERISCOPE
□THEN TARGET DETECTION
□AND DISPLAY ENEMYSUB
□!
□RULE VISUAL TORPEDO
□IF DETECTION IS VISUAL
□AND TARGET IS TORPEDO WAKE
□THEN TARGET DETECTION
□AND DISPLAY TORPEDO
□
□
□RULE ESM TARGET ACQUISITION RADAR
□IF DETECTION IS ESM
□AND ESM DETECTION IS TARGET ACQUISITION RADAR
□THEN TARGET DETECTION
□AND DISPLAY ENEMYSUBID
□!
□RULE ESM MISSILE GUIDANCE RADAR
□IF DETECTION IS ESM
□AND ESM DETECTION IS MISSILE GUIDANCE RADAR
□THEN TARGET DETECTION
```

```
□AND DISPLAY MISSILEID
□
□
□RULE TORPEDO PASSIVE DETECTION
□IF DETECTION IS PASSIVE SONAR
□AND RECEIVED FREQUENCY INDICATES TORPEDO
□THEN TARGET DETECTION
□AND DISPLAY TORPEDO
□
□RULE PASSIVE SONAR DETECTION
□IF DETECTION IS PASSIVE SONAR
□THEN POSSUB DETECTION
□AND DISPLAY POSSUBPASSIVE
□
□
□RULEDISPATCH
□IF ASSET IS HS
□OR ASSET IS VP
□OR ASSET IS SUBMARINE
□AND POSSUB DETECTION
□THENLOCALIZE
□AND DISPLAY DISPATCH
□
□RULE LOCALIZE
□IF POSSUB DETECTION
□ANDLOCALIZE
□AND SUBMARINE TARGET has been LOCALIZED
□THEN TARGET DETECTION
□AND DISPLAY SUBLOCALIZED
□
□
□RULE ACTIVE SONAR DETECTION
□IF DETECTION IS ACTIVE SONAR
□THEN TARGET DETECTION
□AND DISPLAY POSSUBACTIVE
□
□
□RULE RADAR DETECTION
□IF DETECTION IS RADAR
□AND TARGET is CLOSING FAST
```

```
□THEN TARGET DETECTION
□AND DISPLAY MISSILEID
□ELSE TARGET DETECTION
□AND DISPLAY POSSUBRDR
□
□
□RULE MAD DETECTION
□IF DETECTION IS MAD
□THEN TARGET DETECTION
□AND DISPLAY POSSUBMAD
□
□|------------------------------                    DISPLAYS-----------
------------------------
□
□DISPLAY EMCONSILENT
□
□
□
□               TRANSMIT ONLY AS AUTHORIZED BY EMCON PLAN IN
FORCE
□
□DISPLAY EMCONACTIVE
□
□
□
□               TRANSMISSIONS AS DEEMED MOST EFFECTIVE AND
PRUDENT
□
□          ENSURE MAXIMUM INFORMATION GAIN WITHOUT OWN
POSITION   DISCLOSURE
□
□DISPLAY noengrls
□
□
□
□
□          NO RLUES OF ENGAGEMENT ARE IN EFFECT! - DAMN THE
TORPEDOES
□
□                              SHOOT AWAY
```

□
□DISPLAYengrls
□
□
□
□ RULES OF ENGAGEMENT WOULD BE DISPLAYED HERE!
□
□ E.G. DETECTION OF MISSILE GUIDANCE RADAR CONSTITUTES
□ AN ACT OF AGRESSION
□
□DISPLAY train
□
□
□
□ ENSURE THAT YOUR ACTIONS ARE IN ACCORDANCE WITH AXP'S/ATP'S
□
□DISPLAY LOOKOUTS
□
□
□
□ BRIEF LOOKOUTS OF ANTICIPATED THREAT
□
□ INFORM AIRBORNE CONSORTS THAT VISUAL DETECTION IS POSSIBLE
□
□DISPLAY VDSBODY
□
□
□
□ LOWER VDS BODY TO MOST ADVANTAGEOUS DEPTH
□ TO MAXIMIZE USE OF DUCTS/CHANNELS
□ IN ACCORDANCE WITH TACTICAL DOCTRINE
□
□DISPLAY TORPEDO
□
□
□

□ TORPEDO-----TORPEDO------TORPEDO
□
□ SELECT TORPEDO EVASION COURSE/SPEED
□
□ ACTIVATE TORPEDO CONFUSION
PROCEDURES
□
□ INFORM CONSORTS
□
□ TAKE BEARING OF TORPEDO ORIGIN TO
ESTABLISH DATUM
□
□DISPLAY ENEMYSUB
□ ENEMY SUBMARINE
□
□ VISUAL BEARING ###
□
□ RANGE APPROXIMATELY ####
MILES/YARDS
□
□DISPLAY ENEMYSUBID
□ ESM DETECTION OF ENEMY SUB BEARING
DEGREES
□
□ SUBMARINE TYPE IS !@#$%^&*()
□
□ INFORM CONSORTS
□
□ ATTEMPT CROSSFIX
□
□!
□DISPLAYMISSILEID
□ MISSILE INBOUND BEARING ###
□
□ MISSILE TYPE IS !@#$%^&*()
□
□ ACTIVATE ANTI-SHIP MISSILE DEFENSE
PROCEDURES
□
□ INFORM CONSORTS

□
□ ESTABLISH DATUM BASED ON LAUNCH
POSITION
□
□
□DISPLAY POSSUBPASSIVE
□
□ POSSUB DETECTED BEARING ### DEGREES -PASSIVE
DETECTION
□
□ ATTEMPT CONFIRMATION
□
□ ATTEMPT LOCALIZATION USING AVAILABLE
CONSORTS
□
□ ATTEMPT TARGET MOTION ANALYSIS
TECHNIQUES
□
□ ATTEMPT SELF CROSSFIX TECHNIQUES IF NO
CONSORTS
□
□DISPLAYDISPATCH
□
□ DISPATCH CONSORTS TO INVESTIGATE AND
LOCALIZE CONTACT
□
□
□DISPLAY SUBLOCALIZED
□
□ SUBMARINE LOCALIZED AT RANGE ##### AND
BEARING ###
□
□ COMMENCE PROSECUTION IN ACCORDANCE WITH
ORDERED TACTICS
□
□
□DISPLAY POSSUBACTIVE
□ ACTIVE SONAR DETECTION POSSUB
□
□ BEARING ###

```
□
□                         RANGE   #####
□
□                          ALERT CONSORTS
□
□                           CONFIRM AND PROSECUTE
□
□
□DISPLAY POSSUBRDR
□                          POSSIBLE SUBMARINE
□
□                         RANGE ####
□
□                         BEARING ###
□
□                          ESM AND SONAR TO BEARING
□
□                           INFORM CONSORTS AND LOOKOUTS
□
□                          PREPARE TO ENGAGE
□
□
□DISPLAY POSSUBMAD
□                          POSSUB MAD DETECTION
□
□                         RANGE ####
□
□                         BEARING ###
□
□                          INFORM CONSORTS
□
□                         DIRECT ASSISTING ASSET
□
□                          PREPARE TO ENGAGE
□
□END
□
```

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